ABSTRACT

Obstructive sleep apnea (OSA) occurs when the muscles and soft tissues in a person's throat collapse and block the airway while sleeping. Airway blockage can be either "partial" or "complete."[1] OSA is characterized by recurrent episodes of collapse in the upper airway that lead to reduced breathing or complete airway blockage and a significant deterioration of blood oxygen saturation during sleep.[2] Patients with apnea have considerable sleep cycle disruption that substantially decreases health, longevity, and cognitive function.[3] The American Academy of Dental Sleep Medicine suggests oral appliance therapy is an effective treatment for OSA.[4] The gold standard for testing sleep cycle disruption is type I polysomnography, a sleep study performed overnight while the patient undergoes continous monitoring by a credentialed technologist in a sleep clinic. Type I polysomnography records the physiological changes that occur during sleep but is unavailable to patients on a nightly basis at home.[5] Many patients, therefore, rely on the subjective opinion of spouses or partners to determine if an individual snores or appears to stop breathing, gasps, or chokes while sleeping. Patients who live alone can be almost entirely unaware of their condition. With the advent of modern wearable fitness trackers, patients now can interpret overnight objective sleep data and quantitatively measure improvements in their sleep. This data can be shared with the treating dentist for a professional assessment of success (or failure) of the oral appliance. This review teaches a dentist to read and interpret wearable fitness tracker sleep data. With this knowledge, dentists objectively measure the success or failure of the oral appliance therapy interventions they have performed for their patients.[6]

EDUCATIONAL OBJECTIVES

1. List the common health risks for obstructive sleep apnea.
2. Discuss the role of dentistry in sleep apnea therapy.
3. Describe the relationship between tracking objective sleep data with commercial wearable technology and its role in assessing the success or failure of dental sleep apnea therapy.
4. Outline how the information in this course can improve patient care outcomes.

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Sleep medicine and dentistry

How to easily and objectively measure whether dental sleep apnea interventions are improving sleep quality with modern fitness trackers

A PEER-REVIEWED ARTICLE | by Eric S. Bornstein, DMD

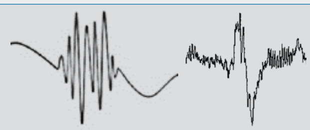
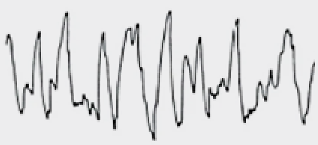
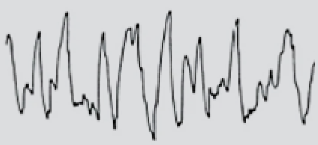
Introduction

When people fall asleep overnight, their "sleep cycle" separates into five stages. Each stage of sleep has clearly distinguishable characteristics along with neural and physiological correlates that differentiate one stage from the others. Table 1 describes these correlates.

Each complete sleep cycle lasts about 90 min. Most adults progress through four to five sleep cycles per evening.[17] The specific order, timing, and duration of each cycle is the sleep architecture, and a sleep hypnogram graphs the architecture cycles.

As such, the hypnogram is a visual description of how sleep stages and architecture are organized throughout recorded sleep intervals. Figure 1 depicts a normal hypnogram,[18] displaying an ideal series of sleep cycles that should occur in an eight-hour sleep period for an adult. This qualitative tool shows the temporal period of each stage of sleep, as well as the number

TABLE 1: Normal stages of sleep

Sleep stage	Normal electroencephalogram (EEG) during sleep	EEG brain wave patterns	Sleep characteristics
Awake	Alpha rhythms		
REM (rapid eye movement) sleep	Beta rhythms[7]		- Active brain - Skeletal muscle paralysis - Dreaming - Rapid eye movements[8]
Stage 1 sleep (transition)	Non-REM alpha waves with theta rhythms[9]		- Transition between awake and sleep - Very light sleep and easy to awaken - Eye twitching, body, and muscle twitching - Stage 1 lasts about five minutes[10]
Stage 2 sleep (light sleep)	Sleep spindles and K-complexes[11]		- Eye movements stop and heart-rate begins to slow - Body temperature begins to lower - Brain wave activity slows down - Stage 2 lasts from 10–20 minutes[12]
Stage 3 sleep (deep sleep)	Delta rhythms[13]		- Difficulty in awakening - Slow brain wave patterns - Growth hormone released - Occurs in the first three to four hours of the night[14]
Stage 4 sleep (very deep sleep)	Delta rhythms[15]		- Deepest sleep - Essential for normal physiologic function[16] - Cardiac and brain healing - Lasts about 30–45 minutes

of transitions between stages. In simple terms, it is a sleep study represented as a graph to illustrate the stages of sleep as a function of time. The most accurate way to track and measure sleep stages and architecture is a study completed in a certified type-1 polysomnography sleep clinic (PSG).

A polysomnography sleep clinic uses multiple technologies that continuously monitor cardiopulmonary and neurophysiological variations in the body. This data illustrates sleep-related phenomena.

These technologies include electroencephalography (brain activity measurement), electromyography (muscle tone measurement), and electrooculography (eye movement) to measure electrical brain activity, muscle tone, and eye movement.

Also, electrocardiography measures cardiac activity, and pulse oximetry measures blood oxygen levels and changing respiration patterns.[19]

Polysomnography data generate simple hypnograms (figure 1) in a sleep clinic or by smartphone software interpreting data collected from modern wearable fitness trackers that are used during a sleep period. These hypnograms can then be examined on a smartphone or the website of a

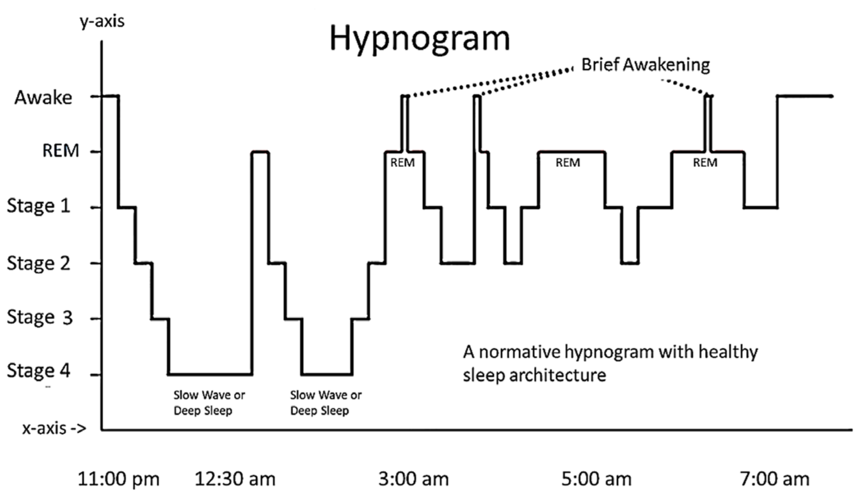


Figure 1: A hypnogram visualizes the organization of sleep stages throughout a recorded sleep period. Sleep architecture is displayed on the plotted hypnogram.

company that manufactures the particular wearable technology.[20, 21]

To accurately track sleep parameters and generate a hypnogram outside of a sleep clinic, one can wear at home a simple sleep-tracking device that incorporates a technology known as photoplethysmography (PPG). This tool uses visible or infrared light generated by a light-emitting diode (LED) on a wearable device to measure heart rate, respiration, and heart rate variability through the skin while a person sleeps.

PPG (depending on the device) is augmented by additional technologies embedded in the wearable, such as accelerometers (to measure how much movement a person makes during sleep), gyroscopes (to assist in measuring sleep stages), temperature sensors, and oxygen saturation monitors.[23]

A variety of commercial devices have such technologies. The data collected are quickly interpreted through smartphone applications and sophisticated software algorithms to generate easy-to-read hypnograms.[24]

In figure 1, a person with normal sleep architecture transitions from a state of being awake to sleep within about 10 min. Stage 1 (transition) typically lasts between one and five minutes. A person then quickly moves into Stage 2 (light sleep), which is just before slow wave or deep sleep. This final stage of non-REM sleep is the deepest sleep stage. Stages 3 and 4 sleep are known as slow-wave, or delta, sleep. A person's physiology, metabolism, and immune system all perform a variety of critical health-promoting tasks during slow-wave sleep.[25-27]

During slow wave sleep (SWS — Stage 3 and Stage 4), arousal from sleep is difficult, heartbeat and breathing are at their slowest rate, and a fully relaxed body has minimal eye movement.

Also during SWS, tissue repair and growth occur with the pulsatile release of human growth hormone from the pituitary gland, and the thyroid gland's secretion of triiodothyronine (T3) and thyroxine (T4) stimulates metabolic lipolysis.[28]

Finally, cell regeneration and autophagy occur along with strengthening the immune system and lowering cortisol levels from the adrenal glands.[29] In the second half of the sleep cycle during REM sleep, eye movements become rapid, and breathing and heart rate increase and become more variable. Also, muscles become paralyzed, brain activity increases markedly, growth hormone pulses cease, and cortisol levels rise with a concomitant rise in heart rate and blood pressure.[30]

Robust SWS is essential for health. During this time, a person experiences the highest levels of thyroid-stimulating hormone and growth hormone from the pituitary gland. Human growth hormone assists in normal physiologic growth, repair, and maintenance of tissues and organs. Triglycerides (liberated from metabolic lipolysis) fuel this function for energy.[31,32]

Also overnight, a regular series of sleep cycles portend healthy circadian peaks in neutrophils and white blood cells, monocytes, basophils, and eosinophils. These peaks occur in the evening as part of routine circadian immune function and maintenance.[33,34] If disrupted sleep occurs for any reason—including sleep apnea—a higher incidence of diabetes, cancer, osteoporosis, and immune-allergic diseases can occur.[35-39]

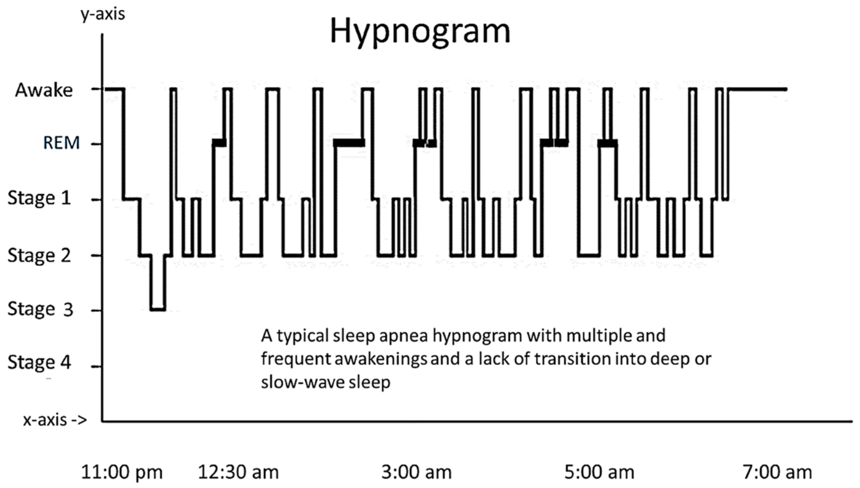


Figure 2: A hypnogram depicting a person with sleep apnea

TABLE 2: Negative health effects of OSA
Decreased slow-wave sleep and hypertension[44, 45]
Obstructive sleep apnea and cognitive decline[46, 47]
Obstructive sleep apnea and insulin resistance[48]
Obstructive sleep apnea and diabetes[49,50]
Obstructive sleep apnea and the risk of ischemic stroke[51]
Obstructive sleep apnea, cardiovascular disease, and pulmonary hypertension[52, 53]
Decreased slow-wave sleep and concomitant immune system dysregulation with accompanying inflammatory disease[54]

Sleep apnea

Sleep apnea is a sleep disorder characterized by frequent pauses in respiration and/or shallow breaths during sleep. The pauses (known as apneas) can last a few seconds or longer and frequently occur throughout the night.[40]

Interpreting a hypnogram[22]

- The format of a sleep hypnogram is based on the time of the measured sleep period. The stages of sleep are a "continuous variable" plotted on the y-axis and time on the x-axis.
- REM (rapid eye movement) or dreaming sleep is at the top under the "awake" stage.
- Stages 1, 2, 3, and 4 sleep are listed under REM.
- The time spent in a given stage of sleep is represented by a horizontal line next to the respective stage of sleep. The length of the horizontal line indicates the time spent in that sleep stage on the x-axis.
- During a transition from one stage of sleep to another, a vertical line is represented on the y-axis of the hypnogram.
- The sleep architecture depicted in a hypnogram is a graphical representation of wake and sleep stages that occurred throughout a measured and recorded sleep period.
- In a normative hypnogram, the first three to four hours of sleep predominantly consists of non-REM, slow-wave (deep) sleep. The second portion of the night consists primarily of REM sleep.
- The time one spends in different sleep stages changes with aging or by sleep interruptions from drugs, sickness, or sleep apnea.

When an apnea terminates, it is associated with a transient arousal from the sleep stage that a person is experiencing. Sleep stage disruption due to apneas and their concomitant arousals often lead to many comorbidities, metabolic disturbance, and inflammatory processes in an individual.[41,42]

Obstructive sleep apnea (OSA) occurs when the muscles and soft tissues in the throat collapse and block the airway while sleeping.[43] Airway blockage can either be "partial" or "complete." Subjective signs of OSA are loud snoring, breathing interruptions witnessed by a partner or spouse, and excessive daytime sleepiness. Figure 2 is an example of a hypnogram depicting a person with sleep apnea.

Numerous health complications occur from OSA and decreased slow-wave sleep. Table 2 shows a partial listing of the health complications.

Sleep apnea management

Sleep apnea usually requires long-term therapy that might include positive airway pressure therapy, oral appliances, and surgery.[55] Other recommendations are behavioral interventions, such as weight loss, smoking and alcohol cessation, body repositioning, and the discontinuation of sedatives.[56]

Oral appliances fabricated and placed by a dentist can improve sleep apnea symptoms.[57-62] Most studies of these dental appliances have strict study conditions, with professional polysomnography as the preferred method of data collection and measurement for improved sleep quality and architecture.

For many patients, the subjective opinion of spouses or partners helps determine if an individual snores or appears to stop breathing, gasps, or chokes while sleeping. The typical patient using a dental OSA device does not spend one or two days per week in a polysomnography sleep clinic to determine the therapeutic efficacy of the device. Also, patients that live alone are often unaware of their OSA condition and are further unaware of any improvement in sleep with an oral apnea therapy device.[63]

With the advent of new photoplethysmography-based fitness trackers, which include accelerometers, gyroscopes, temperature sensors, and oxygen saturation monitors, patients now learn to read and interpret their overnight sleep data that are collected by a fitness tracker via a smartphone (table 3). Patients can then *objectively measure* improvements in their sleep on a nightly basis with dental appliance intervention (objective data in this discussion is data measured by a wearable device and quantitatively interpreted by smartphone software free from opinion, supposition, or faulty recollection, i.e., subjective data).[64, 65]

TABLE 3: Data collection methods and interpretations

Wearable data collection	Wearable data interpretation
Sleep architecture and quality with a hypnogram	The hypnogram illustrates deep sleep, REM sleep, and light sleep values and transitions every night.[66]
Sleep score	The smartphone application on selected technologies assesses the quality of a sleep period[67-70] with a numerical score based on: - the length of each sleep stage - an overnight increase or decrease in temperature - an overnight increase or decrease in heart rate - continuous blood oxygen saturation
Blood oxygen sensing (SpO_2).	Data describes when a patient is experiencing breathing disturbances.[71, 72]
Heart rate variability (HRV)	This is an indicator (based on age) of recovery status, overall health, and fitness level. Specifically, the HRV trend reflects past days' strain and rest levels. The HRV balance captures how the health of the autonomic nervous system (ANS) trends over time. A higher HRV signifies rest and health, and a lower HRV indicates poor rest and recovery.[73-75]

Heart rate variability

The average human heart beats about 72 times/min.[76] Heart rate variability (HRV), a frequently used method, measures a patient's autonomic nervous

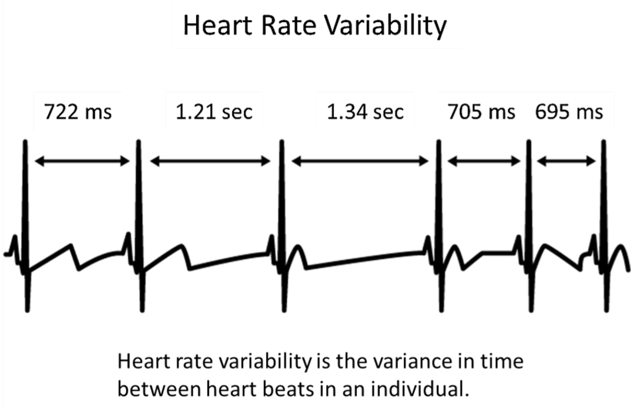


Figure 3: In a generally healthy individual, the physiological phenomenon of variation in the time interval between heartbeats is measured as the *beat-to-beat interval*, and its average is the HRV.[79]

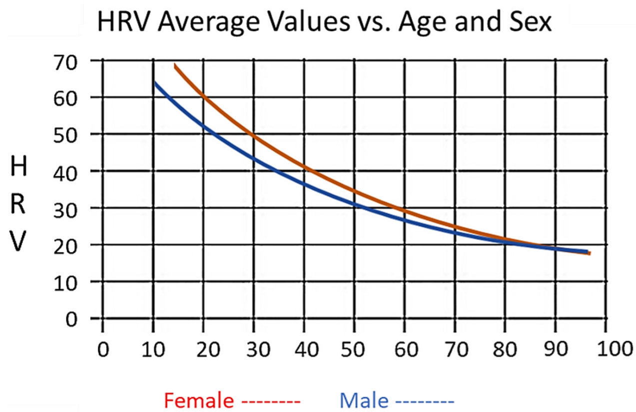


Figure 4: Correlation of HRV data published in the literature for men and women over a person's lifetime.[83, 84]

system (ANS) health.[77] Within the heart rhythm of an individual exists dynamic temporal fluctuations. Variations in the ANS cause the fluctuations.

The ANS includes the sympathetic nervous and parasympathetic nervous systems. The sympathetic nervous system (fight or flight) promotes a higher heart rate, and the parasympathetic nervous system (rest and digest) promotes a lower heart rate.[78] In a generally healthy individual, the physiological phenomenon of variation in the time interval between heartbeats is measured as the *beat-to-beat interval*, and its average is the HRV.[79] See figure 3.

If the average HRV number is higher, this indicates that the ANS is effectively regulating the individual's sympathetic and parasympathetic responses, and that individuals are healthier, and have better control of their ANS. The HRV is also highly dependent on a person's age.[80] In the second decade of life, HRV is about 50–60 ms. As a person ages, the HRV decreases to 20–25 ms.[81]

The HRV in women is marginally higher than in men. However, the difference generally disappears after a woman reaches menopause.[82] See figure 4 for average values of HRV as a function of sex and age.

HRV analyses show a higher parasympathetic nervous system (rest and digest) tone during normal Stage 3 and Stage 4 sleep (i.e., SWS), which elevates the average HRV. A concurrent and elevated sympathetic control during REM sleep lowers the HRV.[85]

Effective OSA therapy should elevate average HRV numbers to a value above the patient's baseline average *before treatment*. Such an increase signals better ANS health and recovery due to successful OSA therapy.[86-89] If the HRV shows no increase, this might signify the potential failure of the OSA therapy. The treating dentist's examination of the combined objective data (sleep score, SpO2, and HRV) will help determine the dental sleep apnea interventions' success (or failure) and whether any adjustments are necessary.[90-95]

Interpreting hypnograms from smart wearables to measure improvements in OSA

As described in table 1 and figure 1, individuals in a normative sleep pattern quickly transition to their first period of SWS within 30 minutes of retiring in bed. A second period of SWS follows within the first three to four hours of overnight sleep. Then at about 3 a.m., in a normative sleep cycle, multiple periods of REM occur when progressively more prolonged periods of REM sleep are interspersed with brief awakenings until the person awakes fully in the morning to begin the day.[96]

The normative sleep architecture of figure 1 contrasts with the typical sleep apnea architecture depicted in figure 2. In the OSA hypnogram (figure 2), minimal SWS shows in the first sleep cycle. Then multiple and frequent awakenings occur with a lack of further transition into SWS or meaningful REM sleep throughout the remainder of the night. These parameters (SWS, REM sleep, and awakenings), captured as objective data, plot on a hypnogram with modern wearable technologies to be then interpreted by smartphone algorithms and software.

Patients use these technologies to objectively track their sleep architecture (and use other quantitative parameters, table 3) to observe sleep improvement or dysregulation on a nightly basis. Studies show that any intervention that increases Stage 3 and Stage 4 sleep (SWS) indicates an improvement in symptoms or lower severity of OSA.[97] See figure 5.

Conclusion

The lack of SWS is thought to be the predisposing factor in the majority of disease states as is the increased morbidity associated with OSA (table 2).

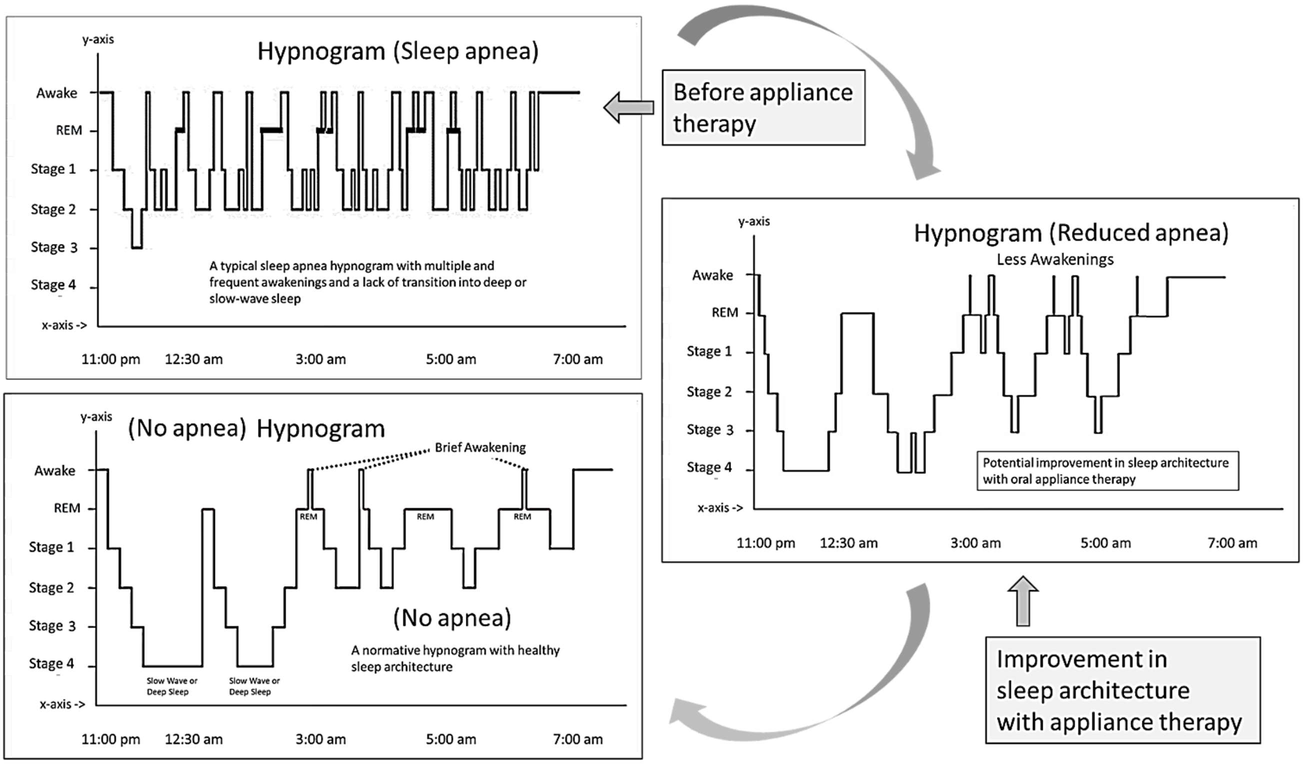


Figure 5: It can be seen that *SWS* (no OSA) and *awakenings* (from OSA) are graphed *as the polar opposites of each other* on a hypnogram. If patients experience Stage 3 or Stage 4 sleep (SWS), then they are not awakening. Conversely, if patients experience multiple awakenings, then they are not experiencing SWS. These data can be used as objective evidence to determine dental OSA interventions' improvement, success, or failure.

With the methods described herein and the correct use of current technologies embedded in today's commercial wearables, a patient and the treating dentist can objectively measure improvement in the patient's OSA during treatment with a dental oral appliance.

The objective measurements consist of a calculated sleep score, SpO2 values, HRV, and a simple hypnogram. The data are invaluable while the dentist decides on the direction of the patient's OSA oral appliance therapy.

These methods also permit dentist and patient to objectively determine what lifestyle changes are necessary, such as weight loss, smoking cessation, alcohol cessation, body position, late eating, and the discontinuation of sedatives.

All of these potential changes (positive and negative) can be tracked quantitatively with the same data collection devices to determine the best way to improve an individual's sleep architecture and decrease OSA episodes.

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1. Obstructive sleep apnea (OSA) occurs when:
   - A. The cartilage in a person's trachea collapses
   - B. The muscles and soft tissues in a person's throat collapse and block the airway while sleeping
   - C. The diaphragm stops functioning
   - D. All of the above

2. OSA is characterized by:
   - A. A significant deterioration of red blood cells during sleep
   - B. A significant deterioration of white blood cells during sleep
   - C. A significant deterioration of blood oxygen saturation during sleep
   - D. A significant deterioration of brain function during sleep

3. The gold standard for testing sleep cycle disruption is:
   - A. Type I polysomnography
   - B. Type 2 polysomnography
   - C. Type 3 polysomnography
   - D. Type 4 polysomnography

4. When a person falls asleep overnight, their "sleep cycle" is separated into:
   - A. 1 stage
   - C. 3 stages
   - B. 2 stages
   - D. 5 stages

5. The sleep characteristics of REM sleep are:
   - A. Active brain waves
   - B. Skeletal muscle paralysis
   - C. Dreaming and rapid eye movements
   - D. All of the above

6. The sleep characteristics of Stage 4 sleep are:
   - A. Transition between awake and sleep
   - B. Eye twitching, body, and muscle twitching
   - C. Sleep spindles
   - D. Cardiac and brain healing

7. Each complete sleep cycle lasts approximately:
   - A. 90 minutes
   - C. 30 minutes
   - B. 60 minutes
   - D. 10 minutes

8. Stage 1 sleep is associated with:
   - A. Alpha waves
   - B. Theta waves
   - C. Alpha and Theta waves
   - D. Delta rhythms

9. During Stage 3 and Stage 4 sleep:
   - A. Heart rate and breathing rate drops
   - B. Heart rate and breathing rate increases
   - C. Dreaming occurs
   - D. OSA occurs

10. Heart rate variability (HRV) is:
    - A. The different size hearts in different individuals
    - B. The physiological phenomenon of variation in the time interval between heartbeats
    - C. The difference measured with different equipment
    - D. None of the above

11. The deepest reparative sleep is:
    - A. Rapid Eye Movement (REM)
    - B. Slow Wave Sleep (SWS)
    - C. Light sleep
    - D. Stage 1 sleep

12. Cortisol levels increase in the
    - A. Evening, together with human growth hormone
    - B. Midafternoon
    - C. Time just before sleep
    - D. Early morning

13. A hypnogram is a visual description of:
    - A. HRV
    - B. The organization of sleep stages and architecture throughout a recorded sleep interval
    - C. Oxygen saturation
    - D. Dreaming score

14. A sleep hypnogram is formatted based on:
    - A. Subjective data
    - B. Decibels of snoring
    - C. The time of the measured sleep period
    - D. All of the above

15. The time spent in a given stage of sleep is represented by ________ in a hypnogram?

A. A horizontal line next to the respective stage of sleep
B. A vertical line next to the respective stage of sleep
C. A diagonal line next to the respective stage of sleep
D. A dashed line next to the respective stage of sleep

16. The sleep architecture depicted in a hypnogram is a graphical representation of:

A. Snoring and choking periods that occurred throughout a measured and recorded sleep period.
B. Wake and sleep stages that occurred throughout a measured and recorded sleep period.
C. Breathing that occurred throughout a measured and recorded sleep period.
D. None of the above

17. In a normative hypnogram, the first three to four hours of sleep predominantly consist of

A. Awakenings
B. Transitions
C. Non-REM, slow-wave (deep) sleep
D. REM sleep

18. To accurately track sleep parameters and generate a hypnogram outside of a sleep clinic, one can utilize:

A. Wearable sleep-tracking devices that incorporate photoplethysmography
B. Wearable sleep-tracking devices that incorporate Blood Oxygen Sensing
C. Wearable sleep-tracking devices that incorporate HRV measurement
D. All of the above

19. Health complications that can occur from OSA and decreased slow-wave sleep are:

A. Hypertension
B. Cognitive decline
C. Insulin resistance
D. All of the above

20. Behavioral interventions to assist in the treatment of OSA include:

A. Weight loss, smoking, and alcohol cessation
B. A warmer sleep environment
C. A sleeping environment with more light
D. A noisier sleeping environment

21. Modern fitness trackers include which technologies:

A. Television and radio reception
B. Accelerometers, gyroscopes, temperature sensors, and oxygen saturation monitors
C. Snoring suppressors
D. None of the above

22. With modern fitness trackers, a patient can _______ measure improvements in their sleep on a nightly basis.

A. Subjectively
B. Emotionally
C. Objectively
D. Psychologically

23. The average human heart beats approximately how many times per minute?

A. 72 times/per minute
B. 60 times/per minute
C. 80 times/per minute
D. 100 times/per minute

24. Heart Rate Variability (HRV) is a frequently used method for testing a patient's:

A. Central nervous system
B. Sympathetic nervous system
C. Parasympathetic nervous system
D. Autonomic nervous system

25. During SWS the average heart rate variability goes:

A. Down
B. Up
C. Stays the same
D. Down only if the heart rate goes down

26. During OSA the average heart rate variability goes:

A. Down
B. Up
C. Stays the same
D. Down only if the heart rate goes down

27. If the average HRV number is higher, the individual is:

A. Healthier and has better control of their ANS
B. Healthier and has better control of their CNS
C. Less healthy and has less control of their ANS
D. Less healthy and has less control of their CNS

28. It can be seen that SWS and awakenings (from OSA) are graphed as:

A. Similar drawings on a hypnogram
B. Polar opposites of each other on a hypnogram
C. Fluid constants on a hypnogram
D. They are not graphed on a hypnogram

29. If a patient is experiencing Stage 3 or Stage 4 sleep (SWS), then they are not:

A. Breathing
B. Rested
C. Awakening
D. In deep sleep

30. If a patient is experiencing multiple awakenings, then they are not:

A. Experiencing SWS
B. Breathing
C. Snoring
D. Experiencing OSA

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EDUCATIONAL OBJECTIVES

1. List the common health risks for obstructive sleep apnea.
2. Discuss the role of dentistry in sleep apnea therapy.
3. Describe the relationship between tracking objective sleep data with commercial wearable technology and its role in assessing the success or failure of dental sleep apnea therapy.
4. Outline how the information in this course can improve patient care outcomes.

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10.	Ⓐ	Ⓑ	Ⓒ	Ⓓ	25.	Ⓐ	Ⓑ	Ⓒ	Ⓓ
11.	Ⓐ	Ⓑ	Ⓒ	Ⓓ	26.	Ⓐ	Ⓑ	Ⓒ	Ⓓ
12.	Ⓐ	Ⓑ	Ⓒ	Ⓓ	27.	Ⓐ	Ⓑ	Ⓒ	Ⓓ
13.	Ⓐ	Ⓑ	Ⓒ	Ⓓ	28.	Ⓐ	Ⓑ	Ⓒ	Ⓓ
14.	Ⓐ	Ⓑ	Ⓒ	Ⓓ	29.	Ⓐ	Ⓑ	Ⓒ	Ⓓ
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RECORD KEEPING. Endeavor Business Media maintains records of your successful completion of any exam for a minimum of six years. Please contact our offices for a copy of your CE credits report. This report, which will list all credits earned to date, will be generated and mailed to you within five business days of receipt.

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Dental Board of California: Provider RP5933. Course registration number CA code: 03-5933-22157. Expires 7/31/2024.
"This course meets the Dental Board of California's requirements for three (3) units of continuing education."

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